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A COMPUTER PROGRAM FOR INTERPOLATION AND PLOTTING OF ISOHYETAL POINTS

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A COMPUTER PROGRAM FOR INTERPOLATION AND PLOTTING OF ISOHYETAL POINTS[1]

M. H. Diskin[2] and P. R. Davis[3]

INTRODUCTION

An important part of the study and interpretation of rainfall records is the preparation of isohyetal maps. Such maps, showing lines of equal depth of rainfall, may be prepared for the total storm rainfall, for rainfall during selected time intervals within the storm, or for rainfall accumulated from a number of storms over a specified period of time such as a month, a season, or a year.

Manual preparation of isohyetal maps is tedious, time consuming, and subjective. The subjectivity is largely due to the interpretation of the original data by the person preparing the map. This is not entirely a disadvantage, since the number of rain-gaging stations is usually less than desirable for preparation of good isohyetal maps, and some human judgment is needed for the production of acceptable or reasonable maps, based on the insufficient data.

Some computer programs for the preparation and plotting of isohyetal maps are commercially available. The programs are, however, expensive both in terms of the initial investment needed to develop or to procure the program and in terms of the computer time needed for the preparation of an isohyetal map. One reason for the complexity and slowness of these programs is the need to provide for all possible combinations of decisions that make up the factor referred to as human judgment.

The compromise between the manual plotting of isohyetal maps and the computer preparation of such maps is a computer program that carries out the tedious and mechanical stage of the map preparation, leaving to the investigator or draftsman the stage in which human judgment is to an advantage. The first of these two stages consists of the interpolation between rain-gaging stations to find points where the rainfall has values equal to integral multiples of the contour interval selected for the map and the plotting of these isohyetal points. The second stage involves the plotting of the isohyets in the form of smooth curves that pass through or near the isohyetal points determined in the first stage.

Assigning the interpolation and plotting of isohyetal points to a computer program also contributes appreciably toward a reduction in the subjectivity of the resulting isohyetal maps. Experience with the preparation of such maps indicates that many of the differences between maps produced by different individuals can be traced to the way they prepare and plot the interpolated isohyetal points. Since this part of the process is tedious and uninspiring, many individuals tend to estimate rather than compute the location of the points and to reduce the number of such points to a bare minimum. The resulting map reflects, of course, the decisions made at this stage. A computer doing this part of the work increases the accuracy of the plotted points and makes it possible to plot all the points needed for the preparation of the isohyetal map. It is even possible to produce more points than are actually needed for the tracing of the isohyets. The extra points are obtained by specifying in the program a smaller contour interval and additional lines of interpolation. They are useful in making the decisions about the most probable configuration of the isohyets.

A program for the interpolation of isohyetal points between rain gages and for the plotting of these points at a desired scale has been developed jointly at the Southwest Watershed Research Center, Agricultural Research Service, and the Department of Agricultural Engineering, University of Arizona. The program is based on two previous programs for the preparation of ground-water-level contour maps developed by the Department of Agricultural Engineering, University of Arizona. A description of the new program, some examples of its use, and information about the computer time needed for its operation are discussed.

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THE INTERPOLATION PROCEDURE

The interpolation procedure adopted for the computer program is the same as that used in manual preparation of isohyetal maps. It consists of a simple linear interpolation along straight lines connecting adjacent stations. Thus, if the depths of rainfall at any two adjacent stations are H_1 and H_2, and the distances from the stations to a point on the line between them are L_1 and L_2, the interpolated depth of rainfall at the point is

$$H = H_1 + \frac{L_1}{L_1 + L_2} (H_2 - H_1) \qquad (1)$$

or

$$H = \frac{L_2 H_1 + L_1 H_2}{L_1 + L_2} \qquad (2)$$

Denoting the distance between the two stations by L, the equations may be solved for the distance along the line from Station No. 1 to a point where the interpolated depth is a given value H.

$$L_1 = \frac{H - H_1}{H_2 - H_1} L \qquad (3)$$

If the stations are specified in terms of their coordinates on a rectangular X-Y axes system (fig. 1), the equations may be rewritten in terms of these coordinates. The equations for the coordinates (X_P, Y_P) of the point where the depth of rainfall is H, corresponding to equation 3, are

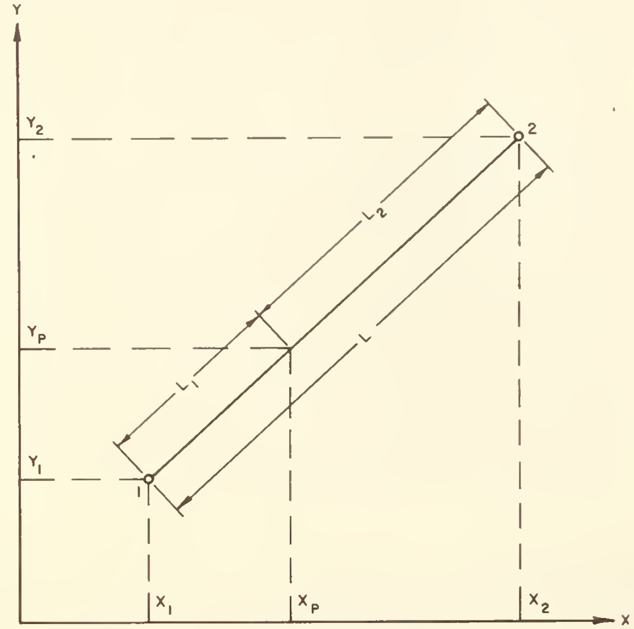

Figure 1.—Interpolation for a line joining two stations.

$$X_P - X_1 = \frac{H - H_1}{H_2 - H_1} (Y_2 - X_1) \qquad (4)$$

and

$$Y_P - Y_1 = \frac{H - H_1}{H_2 - H_1} (Y_2 - Y_1) \qquad (5)$$

The equations are, of course, not restricted to points between the two rain-gaging stations. They may be used also for extrapolating to points situated on the straight line joining the stations but outside the intercept defined by the two stations.

The first step in the application of the above interpolation procedure to the preparation of an isohyetal map is the construction of a network of lines connecting adjacent stations. This network, which may be called the interpolation network, is composed of an assembly of lines along which the interpolation procedure is applied. Ideally, the interpolation network would be composed of an assembly of equilateral triangles (fig. 2a), which could be obtained if the rain-gaging stations were situated on a triangular grid. In practice, this

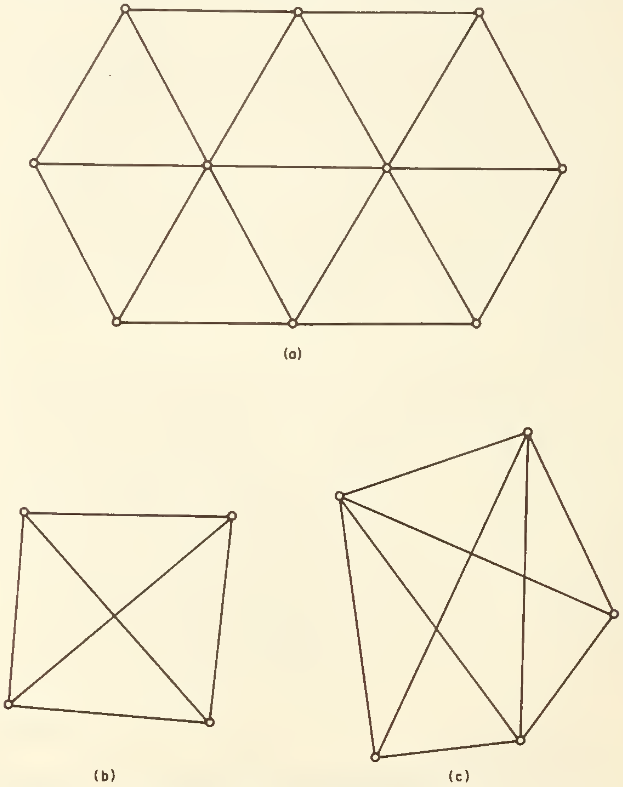

Figure 2.—Various shapes of interpolation networks: (a) equilaterial triangles, (b) four-sided polygons, and (c) five-sided polygons.

configuration is very rare, and the network will usually be composed of four- or five-sided polygons, for which interpolation may be carried out along two or more intersecting diagonals (figs. 2b and 2c).

Interpolated values of the depths of rainfall at the point of intersection of any two diagonals will usually not be equal, depending on the values of rainfall at the stations joined by these diagonals. In the manual preparation of isohyetal maps, one line (or at least a part of the line) of each pair of intersecting diagonals is frequently ignored. The decision of which diagonal to ignore is often arbitrary and may lead to errors in the final map. With a computer interpolation program, it is possible, however, to include all diagonals and to obtain interpolated values along all such lines. The decision to reject any interpolated point or a group of such points can be made at a later stage when all the points are available for inspection. It should be noted that in different rainfall events the rejected points will be located in different parts of the interpolation network, depending on the pattern of rainfall recorded at the rain-gaging stations.

DESCRIPTION OF THE COMPUTER PROGRAM

The computer program developed is made up of three major divisions: (1) The first examines the data and computes the coordinates of interpolated points along lines of the interpolation network as specified in the input data; (2) the second rearranges the interpolated points and the rain-gaging station in the order of the magnitude of their X or Y coordinates as a preparation for the plotting; (3) the third plots the rain-gaging stations and the interpolated points in their locations relative to a rectangular grid at the scale chosen for the map. More details about the three divisions are given in the following paragraphs. A flow chart of the computer program is given in figure 3.

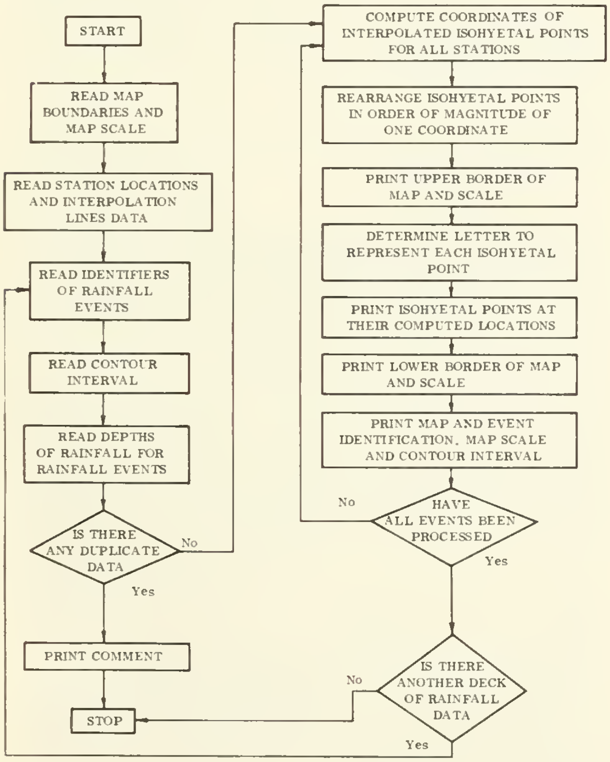
START
READ MAP BOUNDARIES AND MAP SCALE
READ STATION LOCATIONS AND INTERPOLATION LINES DATA
READ IDENTIFIERS OF RAINFALL EVENTS
READ CONTOUR INTERVAL
READ DEPTHS OF RAINFALL FOR RAINFALL EVENTS
IS THERE ANY DUPLICATE DATA
No
Yes
PRINT COMMENT
STOP
COMPUTE COORDINATES OF INTERPOLATED ISOHYETAL POINTS FOR ALL STATIONS
REARRANGE ISOHYETAL POINTS IN ORDER OF MAGNITUDE OF ONE COORDINATE
PRINT UPPER BORDER OF MAP AND SCALE
DETERMINE LETTER TO REPRESENT EACH ISOHYETAL POINT
PRINT ISOHYETAL POINTS AT THEIR COMPUTED LOCATIONS
PRINT LOWER BORDER OF MAP AND SCALE
PRINT MAP AND EVENT IDENTIFICATION, MAP SCALE AND CONTOUR INTERVAL
No
HAVE ALL EVENTS BEEN PROCESSED
Yes
No
IS THERE ANOTHER DECK OF RAINFALL DATA
Yes

Figure 3.--Flow chart for computer program.

In the first division, the input data are examined to determine if the coordinates of any station are given more than once or if there is more than one value of rainfall per storm for any of the gages. If either of these cases occurs, the program will print a note that there are duplicate data and will stop. During the preliminary examination of data, the program also detects the presence of: (1) gages for which coordinates are available with no rainfall data, or (2) gages for which the rainfall is given but no coordinates are available. In either case, a note will be printed giving the number of the gage affected, but the program will continue with the computations for the gages for which the data are complete. Stations with zero rainfall are treated the same as any other station. During execution of the first division, notes will also be printed giving the number of any gage for which interpolation cannot be completed because of either of the above reasons.

After examination of the input data, the program computes the coordinates of the interpolated isohyetal points. The depths of rainfall for the isohyetal points are taken at integer multiples of the contour interval specified for the map, and the coordinates are computed by equations 4 and 5. Interpolation is done along the lines specified, proceeding from the station with lower rainfall to the station with the higher rainfall. Isohyetal points falling outside the segment defined by the two stations are also included, to avoid loss of information, if their distance from the stations is less than 3 percent of the distance between the stations or two plotting increments, whichever is longer. No interpolation will be carried out between two stations for which the absolute value of the difference in depth of rainfall is less than 0.001 of the contour interval. The interpolation procedure is applied to each station on the watershed in turn. Each of the stations can have up to four adjacent stations to which the interpolation will be carried out.

In the second division, the program considers all the isohyetal points generated in the first part, as well as all gaging stations used in the interpolation process, and prepares them for the third part of the program. All points in these two groups are rearranged in a decreasing order of the value of their Y coordinate. If a rotation option has been specified, whereby the map is to be rotated by 90° before printing, the rearrangement is done with respect to an increasing value of the X coordinate.

The list of stations used in the interpolation procedure, as well as their coordinates, and the values of the depth of rainfall for the storm considered are printed during the second division of the program. Another list of interpolated points rearranged as described above, can also be printed at this stage if a print option is specified.

In the third division, the program prepares and plots the map consisting of rain-gaging stations and interpolated isohyetal points plotted at their proper locations according to the scale of the map used. An example of the map produced is given as figure 7 in the section, Applications of the Program. The rain-gaging stations are represented by asterisks (*), and the isohyetal points are represented by letters of the alphabet (A, B, C, D, etc.). The letter printed at each point represents the value of the isohyet passing through that point. Thus, the letter A represents points for which the interpolated depth of rainfall is equal to one isohyetal interval, the letter B represents points for which the depth of rainfall is equal to two isohyetal intervals, etc. Points with zero rainfall are indicated by the letter "Z." The same letter is used also for points where the depth of rainfall is equal to 26 isohyetal intervals. If the range of rainfall values to be represented is more than 26 isohyetal intervals, the sequence of letters repeats itself.

The map is plotted at the scale specified, with the X axis across the printed page of output and values of X increasing from left to right. The Y axis is down the printed page and is continuous from one page to the next. Values of Y increase from the bottom of the page upwards. If the range of X values exceeds the width of the printed page, additional strips of the map will be produced so that the full range of X values is covered. An option is available in the program to rotate the axes clockwise by 90° so that the Y axis runs across the page and the X axis is perpendicular to the width of the printed page.

Identification of the watershed, the storm event, the scale of the map, and the contour interval used are printed below the map. The axis parallel to the width of the paper is labeled as the X axis or, if the map has been rotated, as the Y axis. Both axes have the scale in miles printed along the borders of the map. The axis across the page has values at 1.0-inch intervals. The axis perpendicular to the width has the coordinate given for each printed line. The value given is the value of the coordinate at the center of the printed line. The number of miles represented by 1 inch is the same along the two axes, so that the map produced is free of distortion.

A listing of the program is given in the Appendix. Copies of the deck of cards of the program are available from the Southwest Watershed Research Center, Agricultural Research Service, Tucson, Ariz. 85705.

CAPACITY AND ACCURACY OF PROGRAM

The computer program in its present form can prepare a map of isohyetal points for networks composed of up to 200 rain-gaging stations. Each of these stations can be the origin of up to four lines to adjacent stations, along which interpolation is carried out. Since each of the lines in the interpolation network needs to be defined only once, it follows that the total number of interpolation lines that originate or end at a given station can be as high as eight. Experience with the program indicated that this number is quite adequate.

The number of interpolated isohyetal points generated by the program can be up to 3,000 minus the number of rain-gaging stations for which coordinates are given. This number allows an average number of at least 14 interpolated points for each rain-gaging station. This appears to be more than adequate.

Both limits given above are controlled by "DIMENSION" and "DO" statements within the program. The two limits may be changed without impairing the performance of the program. The program length with the above limits is about 62,200 (Octal) including input and output buffers.

The accuracy of the plotting of the locations of interpolated points and of the rain-gaging stations depends on the scale chosen for the map. The plotted points are represented by printed letters on the output printer of the computer. The maximum error possible in the true location of the interpolated points in a direction parallel to the width of the paper is therefore half the spacing of the letters. The maximum error of plotting in the direction perpendicular to the width is equal to half the spacing between the centers of printed lines.

The program was written for a printer producing 6 lines per inch down the page and 10 characters per inch of printed line. Thus, the area represented by any one letter has the dimensions

$$\mathrm{DELX} = \mathrm{SCALE}/10.0 \qquad (6)$$

and

$$\mathrm{DELY} = \mathrm{SCALE}/6.0 \qquad (7)$$

across and down the page, respectively. In these equations, "SCALE" stands for the number of miles represented by 1 inch on the map. If the program is run on a computer having different spacings, the program instructions corresponding to equations 6 and 7 must be changed to agree with the spacings of lines and letters in the computer used. If the number of letters is other than 10 characters per inch, changes will also be necessary in the part of the program that arranges for the printing of the upper and lower borders of the map and the scales printed with them.

The computed locations of two or more isohyetal points may be such that the letters representing them should be printed at the same location. To avoid loss of information resulting from the printing of only one of the letters, provision is made in the program to print the second character one plotting increment to the right of the position where it should have been printed. If the two locations are occupied, the point will be plotted to the left of the original location. The maximum plotting error for a letter that is part of a group of adjacent letters may thus be as much as 1.5 plotting increments from its true position.

The accuracy of plotted isohyetal points can obviously be increased by using a larger scale (smaller number of miles per inch). The accuracy of drawing the isohyetal lines depends on the number of interpolated points available. It was found that the accuracy of the isohyets can be improved by specifying a contour interval equal to half the contour interval needed in the final map and then, after plotting, discarding the lines not needed.

In summary, it appears that best results can be obtained with the program by specifying a larger scale and a smaller contour interval than needed for the final isohyetal map. After plotting the isohyets on the computer output sheets, only those contours at the prescribed contour interval are copied and reduced in size to the scale needed.

INPUT AND OUTPUT OF PROGRAM

The program in its present form can handle an unlimited number of events for which isohyetal maps are required for a given watershed. A series of isohyetal maps will be produced, one for each rainfall event. All maps will be produced at the same scale, and each will be accompanied by tables and other pertinent information as described herein.

The structure of the input data deck and the format used for the various cards are described below with reference to figure 4. The deck is made up of two main parts: Part A (fig. 4) contains information about the network of rain-gaging stations; Part B contains information about the rainfall events to be plotted. Part B may be repeated as often as needed to include all rainfall events for which isohyetal maps are required. The types of cards used for the input data deck are described below. The numbers preceding the following paragraphs correspond to the numbers of the various cards shown in figure 4.

1. The first card contains information about the watershed and the rainfall events to be plotted. The message TITLE, which may contain up to 80 alphanumeric characters, will be printed with the isohyetal map and the tables accompanying it. The card format is (8A10).
2. The second card controls the size and scale of the map to be produced. It contains the following information:

   a. YMIN, YMAX, XMIN, XMAX–minimum and maximum values of Y and X, respectively. These values determine the borders of the map produced.

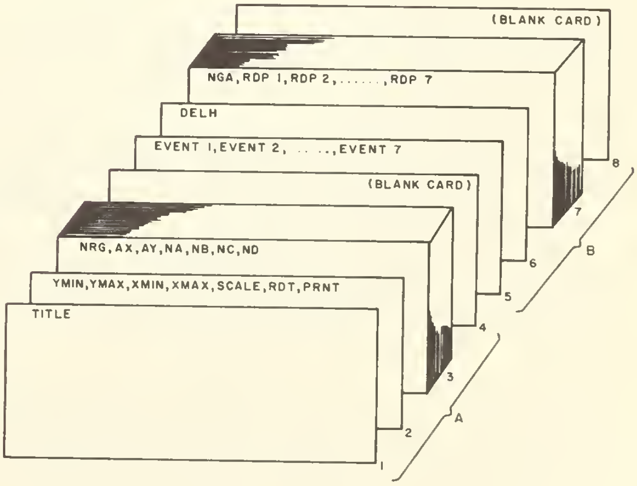
(BLANK CARD)
NGA, RDP 1, RDP 2, ..., RDP 7
DELH
EVENT 1, EVENT 2, ..., EVENT 7
(BLANK CARD)
NRG, AX, AY, NA, NB, NC, ND
YMIN, YMAX, XMIN, XMAX, SCALE, RDT, PRNT
TITLE
1
2
3
4
5
6
7
8
A
B

Figure 4.–Structure of deck of cards containing input data.

   b. SCALE– the number of miles represented by 1.0 inch on the map. This value determines the size of the map.

   c. ROT– a variable indicating if rotation of the axes is needed. A value of zero or a blank entry will cause no rotation. Any value other than zero will cause a clockwise rotation of the axes by 90°.

   d. PRNT– a variable controlling the printing of a table of interpolated data points. A zero value or a blank entry will suppress the printing of the data. Any other value will cause the printing of a table giving the coordinates and rainfall depth for all interpolated points.

   The format of card No. 2 is (8F10.0).

3. The deck of cards following card No. 2 describes the rain-gaging station locations and the definitions of the lines along which interpolations will be made. One card containing the following information is provided for each station.

   a. NRG–the identifying number of the rain-gaging station.

   b. AX, AY–the X and Y coordinates of the rain-gaging stations.

   c. NA, NB, NC, ND–the identifying numbers of the adjacent four stations defining lines in the interpolation network. If fewer than four station numbers are given, interpolation will be made only to numbered stations as provided.

   The format of these cards is (I10, 2F10.0, 4I5).

4. The card following the station-description cards is a blank card signifying the end of these cards.

5. The first card of part B of the input deck is a card identifying the individual events for which isohyetal maps will be prepared. One to seven events may be included, with each event being identified by a 10-character alphanumeric word, EVENT. The event identifiers will be printed with the isohyetal maps and tables. The format of the card is (7A10).

6. The second card of part B specifies the contour interval, DELH, to be used for computing the isohyetal points. The same contour interval will be used for all events listed on the previous card. The format of the card is (F10.0).

7. The deck of cards following the contour interval card contains rainfall depth data for the one to seven events for all rain-gaging stations. Each card has the identifying number of one station, NGA, and the corresponding rainfall depth, RDP, for the events for which maps are to be prepared. Each station must have a record for each of the events since a blank entry is interpreted as zero depth of rainfall. Stations for which no cards are provided will be ignored. The format of cards in this deck is (I10, 7F10.0).

8. The last card is a blank card signifying the end of the depths-of-rainfall cards.

The number of rainfall events included in part B of the input deck may be less than the seven events for which space is provided. The events included must, in this case, occupy the corresponding number of positions on card Nos. 6 and 7, starting from the left-hand side of the cards. A repetition of part B of the input deck may follow the original deck even if the number of events in the original deck was less than seven.

The A10 format of card Nos. 1 and 5, used to supply identification information, is the largest allowed on the computer available. In adapting the program to another computer, these formats may have to be changed to agree with the capacity of the computer used.

The output of the program is self-explanatory. It consists of the following sections, each starting at a new page of output.

1. The first section contains information about the identification of the watershed, boundaries specified for the map, and the scale used.

2. The identifications of the watershed and of the event considered, and a list of comments, if any, that were produced during the first division of the program are printed in the second section.

3. The third section lists a table of the original data used for the interpolation, giving coordinates and depth of rainfall for each station. Also included in this section is a statement about the contour interval and the number of rain-gaging stations used.

4. Section 4 contains a table of interpolated data, giving coordinates and depth of rainfall for all isohyetal points interpolated by the program. The points are arranged by decreasing value of the Y coordinate or increasing value of the X coordinate. The table is followed by a statement of the number of interpolated points. The table of interpolated data will be

suppressed unless the print option is chosen. If the table is not printed, the statement about the number of interpolated points will be printed with section 3.

5. Section 5 is a map of isohyetal points represented by letters of the alphabet and stations represented by asterisks, all plotted at their locations according to the scale selected. The map is followed by identification statements and notes concerning the scale of the map and the isohyetal interval.

6. An "end of data" statement is printed in section 6 if all data have been processed and the exit is normal. If the program is stopped because of duplicate data, a statement to this effect will be printed.

APPLICATIONS OF THE PROGRAM

The use of the computer program will be illustrated with data for the storm of July 28, 1966, on the Walnut Gulch watershed. The area for which the isohyetal map will be prepared is part of the main Walnut Gulch watershed, contributing to measuring flume No. 11 (watershed No. 63.011). The boundaries of the subwatershed and the locations of rain-gaging stations on and near the boundaries of the watershed are shown in figure 5.

The first step in using the program involves joining adjacent rain-gaging stations to produce the interpolation network. The network for the stations included in figure 5 is shown in figure 6. The first part of the input data deck (part A of fig. 3) is prepared from information in figures 5 and 6. It includes map boundaries, rain-gaging stations, coordinates from figure 5, and definitions of interpolation lines from figure 6. Part B of the input data deck, containing rainfall data for the evening storm of July 28, 1966, is prepared from the precipitation records for the rain-gaging stations. The two parts of the input data deck are listed in table 1.

The output of the computer program is shown in table 2 and in figure 7. Table 2 gives the information printed as sections 1 and 3 of the output, and figure 7 is a reproduction of the map of isohyetal points produced in section 5 of the computer output. Figure 8 shows the same map with the isohyetal lines drawn through the isohyetal points. The final isohyetal map for watershed

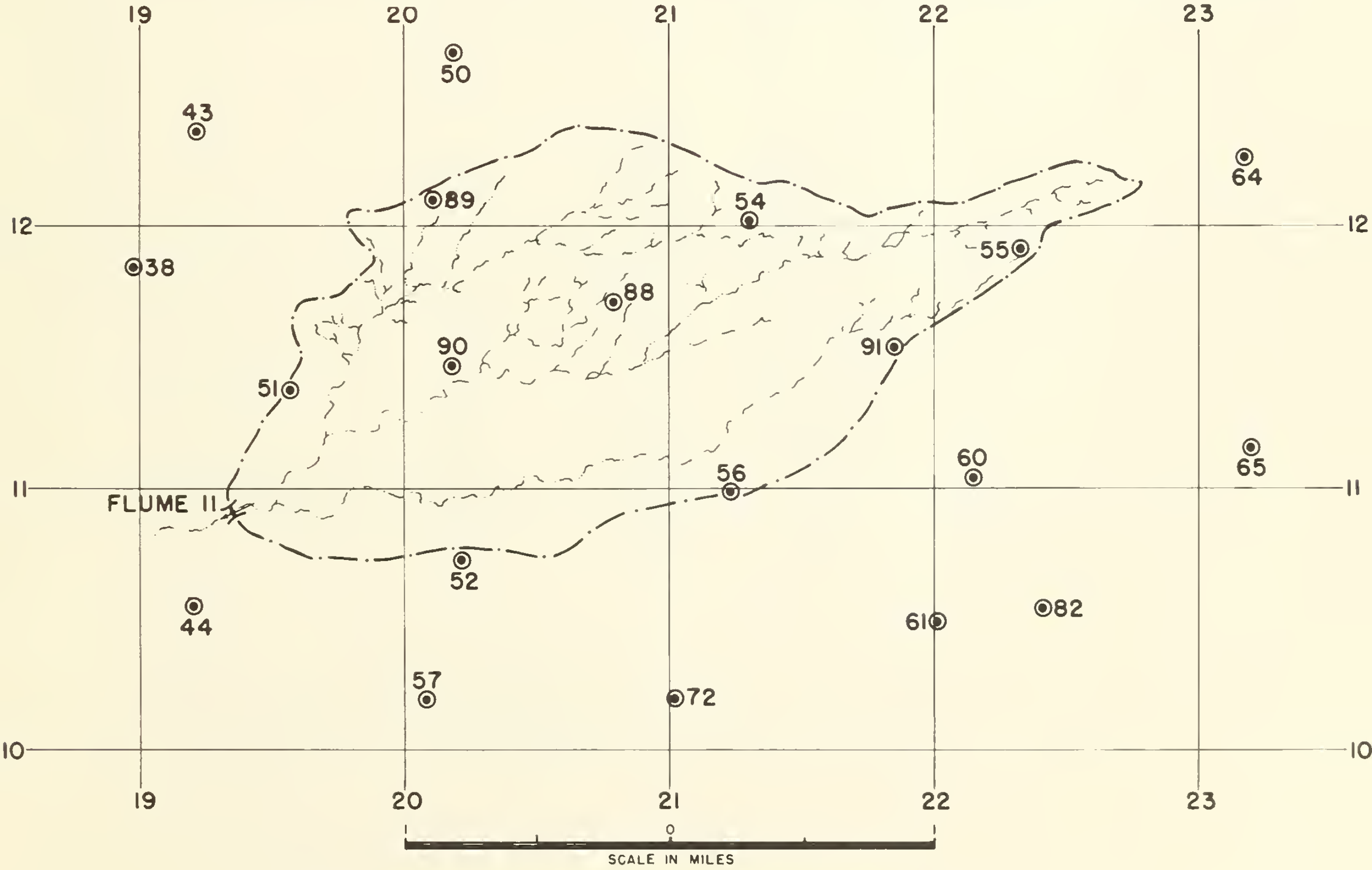

Figure 5.–Coordinate system, rain-gaging stations and boundaries for watershed 63.011.

TABLE 1.–Listing of input data deck

Input deck part	Card type	Listing of Cards						
A	1	Walnut Gulch Watershed Above Flume No. 11						
	2	10.0	13.0	18.6		23.3		0.40
	3	38	18.965	11.820	43			
		43	19.200	12.335	51	90	89	
		44	19.195	10.540	38			
		50	20.180	12.645	43	89	88	55
		51	19.565	11.360	38	44	57	52
		52	20.210	10.715	90	44	57	72
		54	21.290	12.020	50	88	56	
		55	22.315	11.915	54	91	60	
		56	21.225	10.980	88	52	72	
		57	20.080	10.185	72	44		
		60	22.140	11.035	56	72		
		61	22.000	10.485	72	56	60	
		64	23.170	12.275	55	60	50	54
		65	23.190	11.150	60	64	55	
		72	21.015	10.190	90			
		82	22.400	10.540	60	61	65	
		88	20.780	11.705	90	89	52	
		89	20.100	12.085	38	51	54	
		90	20.170	11.465	51	89	56	
		91	21.840	11.540	60	54	88	56
	4							
B	5	July 28 66						
	6	0.1						
	7	38	1.28					
		43	0.88					
		44	1.34					
		50	1.12					
		51	1.08					
		52	1.43					
		54	1.88					
		55	2.23					
		56	1.68					
		57	1.55					
		60	1.93					
		61	2.01					
		64	2.15					
		65	2.07					
		72	2.12					
		82	2.18					
		88	1.54					
		89	1.01					
		90	1.19					
		91	1.94					
	8							

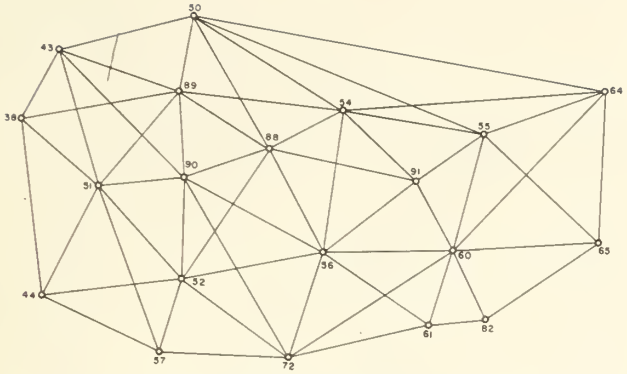

Figure 6.—Interpolation network for rain-gaging stations on and near watershed 63.011.

63.011, prepared on the basis of the points produced by the computer, is shown in figure 9. The area represented in figure 9 is only part of the area shown in figure 8.

The computer time needed to run this program on the CDC[4] 6400 computer, using Fortran IV language, at the University of Arizona was 5.5 seconds on the central processing unit and 20.4 seconds on the peripheral processors. These times include the compiling of the program, which took 3.9 seconds on the central processing unit and 14.4 seconds on the peripheral equipment.

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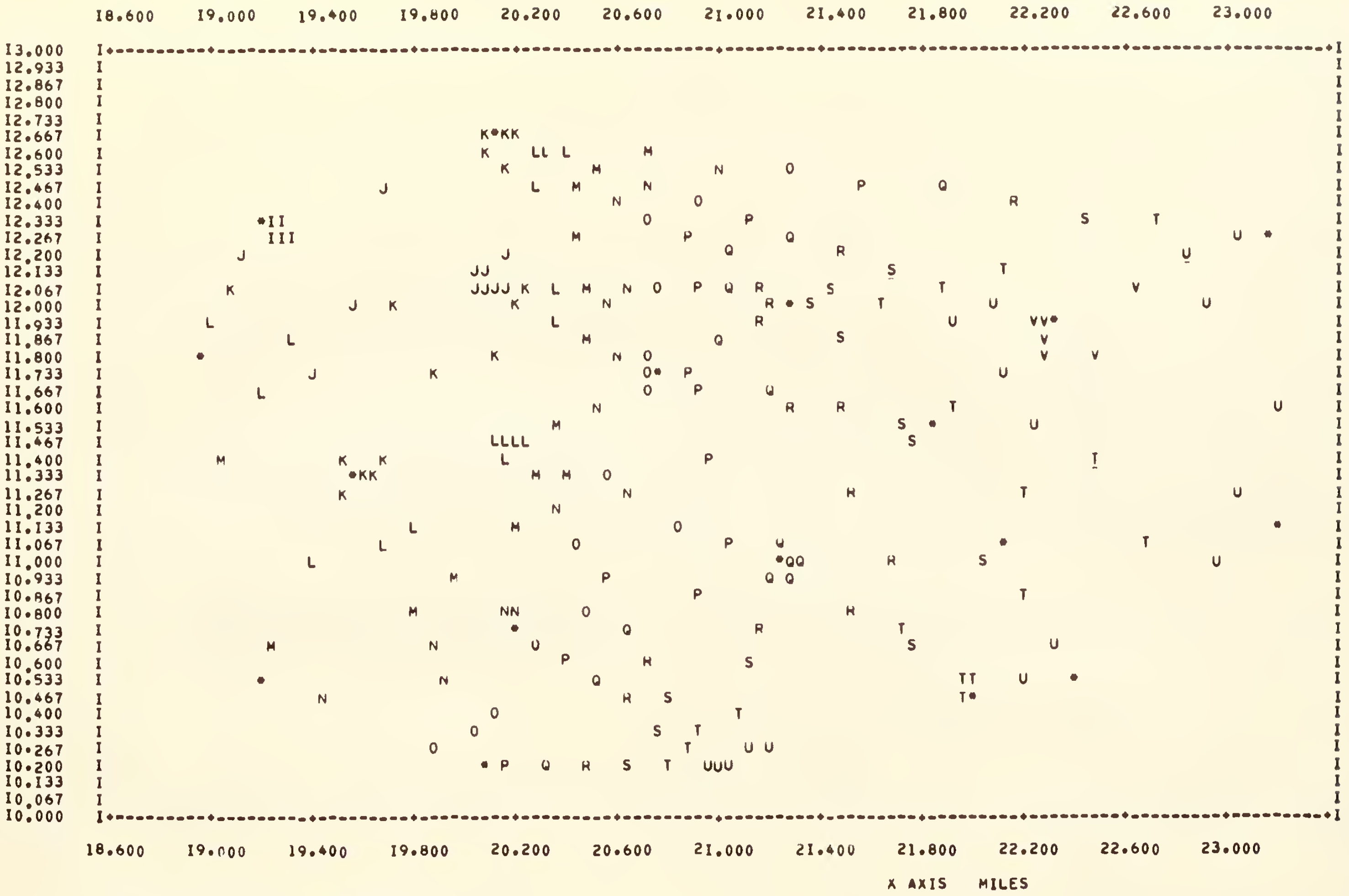
[4] Use of a trade name does not imply endorsement by the U.S. Department of Agriculture. It is used only for the purpose of providing specific information to readers.

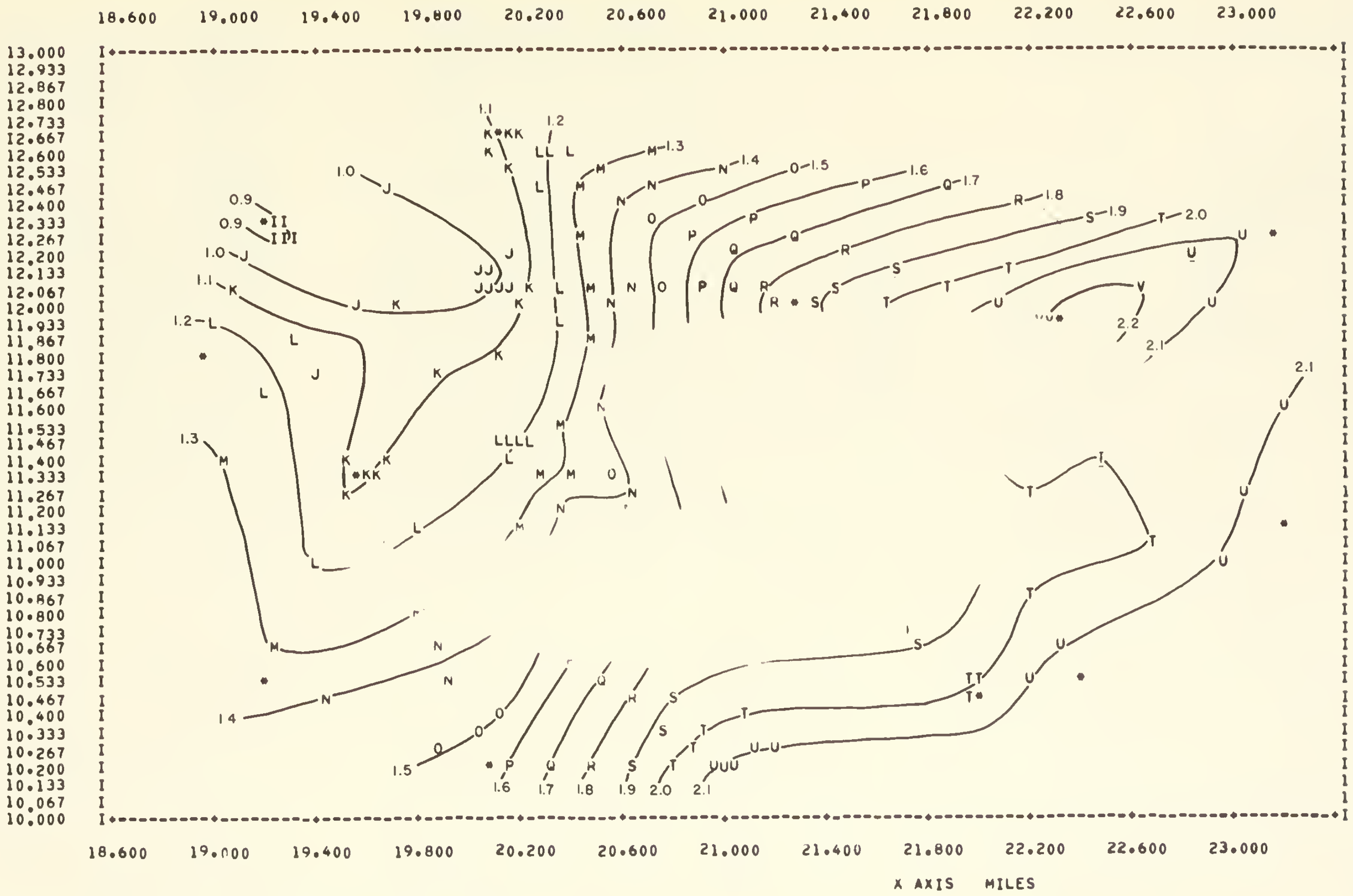
TABLE 2.—Output of computer program

```
                     Walnut Gulch Watershed Above Flume No. 11

   YMIN          YMAX          XMIN          XMAS          SCALE
  10.0000       13.0000       18.6000       23.3000        .4000

                     Walnut Gulch Watershed Above Flume No. 11

  July 28 66


                   ORIGINAL DATA USED FOR INTERPOLATION

                   RG          X             Y            RAIN

                   38       18.9650       11.8200        1.2800
                   43       19.2000       12.3350         .8800
                   44       19.1950       10.5400        1.3400
                   50       20.1800       12.6450        1.1200
                   51       19.5650       11.3600        1.0800
                   52       20.2100       10.7150        1.4300
                   54       21.2900       12.0200        1.8800
                   55       22.3150       11.9150        2.2300
                   56       21.2250       10.9800        1.6800
                   57       20.0800       10.1850        1.5500
                   60       22.1400       11.0350        1.9300
                   61       22.0000       10.4850        2.0100
                   64       23.1700       12.2750        2.1500
                   65       23.1900       11.1500        2.0700
                   72       21.0150       10.1900        2.1200
                   82       22.4000       10.5400        2.1800
                   88       20.7800       11.7050        1.5400
                   89       20.1000       12.0850        1.0100
                   90       20.1700       11.4650        1.1900
                   91       21.8400       11.5400        1.9400

                   INTERVAL BETWEEN ISOHYETS = .100 INCH

             THE NUMBER OF RAIN-GAGING STATIONS USED is 20

                THE NUMBER OF INTERPOLATED POINTS IS 189
```



```
     WALNUT GULCH   WATERSHED ABOVE FLUME NO. II
JULY 28 66


SCALE OF MAP      .4000  MILES = I INCH                          INTERVAL BETWEEN ISOHYETS =     .100  INCH


RAIN GAGE LOCATION DENOTED BY   *
ISOHYETAL POINTS DENOTED BY LETTERS
```

Figure 7.—Map of isohyetal points printed as computer output.



```
   WALNUT GULCH   WATERSHED ABOVE FLUME NO. 11
JULY 28 66


SCALE OF MAP      .4000  MILES = 1 INCH                    INTERVAL BETWEEN ISOHYETS =     .100  INCH


RAIN GAGE LOCATION DENOTED BY    *
ISOHYETAL POINTS DENOTED BY LETTERS
```

Figure 8.–Computer output with isohyetal lines.

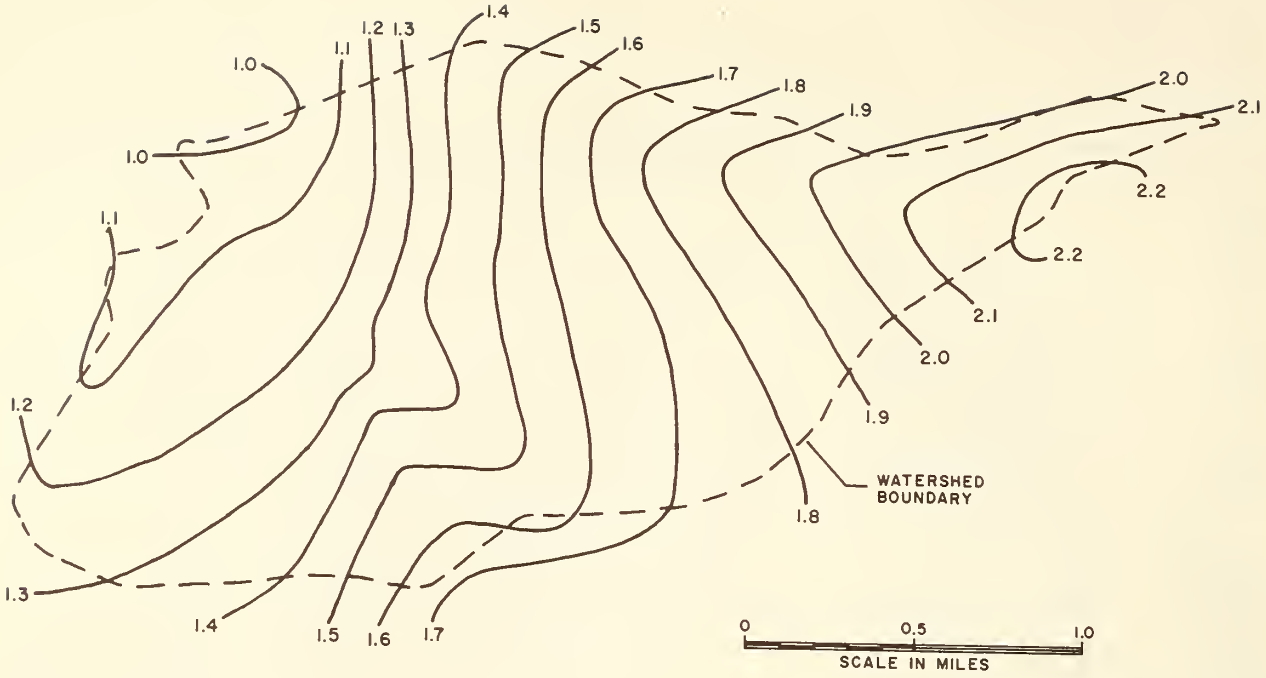


Figure 9.–Isohyetal map for storm of July 28, 1966, (1900) on watershed 63.011.

The net time for the preparation of the map is thus 1.6 seconds on the central processing unit and 6.0 seconds on the peripheral processors.

The following information is given as another example of computer time needed to run the program. The preparation of a map of isohyetal points for storms on the Walnut Gulch watershed (63.001) based on data from 90 rain-gaging stations took, exclusive of compiling time, about 5.6 seconds per storm on the central processing unit and about 9.6 seconds per storm on the peripheral processors. The area of the watershed is 57.7 square miles. The scale of the map produced was 0.75 mile per inch, and the contour interval was 0.2 inch. The number of interpolated points was about 400 per storm.

The computer program has been applied to a number of storms on a few watersheds with satisfactory results. In another application it was used to determine the distribution of vegetation and soil composition on a watershed. The percentage of soil constituents and the density of given species of vegetation were used as the variables to be plotted, rather than the rainfall depth. The program can be used also for plotting of ground-water-table contours, lines of equal depth to groundwater, equal-temperature lines, or in fact maps of any variable that is a function of location.

CALCULATION OF VOLUME

The computer program for plotting isohyetal points does not and cannot compute the average depth of rainfall or the volume of rainfall deposited on the area represented by the map. The reason is that the map produced contains only isolated isohyetal points, whereas the complete isohyets are needed for the computation of the average depth of rainfall.

It is generally agreed that the average depth of rainfall derived from an isohyetal map, prepared by the conventional interpolation methods, is very nearly equal to the average depth of rainfall computed by Thiessen weights. If the isohyetal maps are to be used for computing the average depth of rainfall, it is necessary to read new input data from the maps for each storm. For computation based on Thiessen weights, all that is needed is a simple program that multiplies the observed depth of rainfall by Thiessen weights computed once for the network of rain-gaging stations.

A computer program for computation of Thiessen weights has been described elsewhere.[5] Copies of the deck of cards of this program are also available from the Southwest Watershed Research Center, Southwest Branch, Agricultural Research Service, Tucson, Ariz. 85705.

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[5] Diskin, M. H. "On the computer evaluation of Thiessen Weights," Jour. of Hydrology 11(1): 135-144, 1970.

CONCLUSION

A computer program has been prepared for computing the locations of isohyetal points and their plotting as part of the printed output of a digital computer. The locations of the points are found by linear interpolation along lines of an interpolation network defined by the input data. The points are plotted as alphabet letters printed at the computed locations for the map scale specified. Each letter signifies a different isohyet according to the contour interval selected.

The map borders have X and Y coordinate scales marked at regular intervals. The map is accompanied by explanatory notes and tables of data. An option is available in the program for rotating the axes by 90° before printing, if this is advantageous for the shape of the watershed considered. The locations of the rain-gaging stations are also included in the map.

The program reduces the manual work involved in the preparation of isohyetal maps. It produces results comparable to or better than the manually prepared maps. The computer time needed for running the program is relatively short. The number of maps prepared in one setting is practically unlimited. In addition to the preparation of isohyetal maps, the program may be used for the preparation of maps of ground-water-table contours and other contour maps useful for hydrological investigations.

APPENDIX

```
      PROGRAM CONPLT (INPUT,OUTPUT,TAPE1=INPUT)
C
C          A PROGRAM TO INTERPOLATE ISOHYETAL POINTS BETWEEN RAINGAGES
C1         AND TO PLOT THE INTERPOLATED POINTS AT A GIVEN SCALE.
C
C          PROGRAM CONPLT WAS WRITTEN BY M.H.DISKIN.
C
C          THE PROGRAM IS BASED ON PROGRAMS CONTOUR AND MAP WRITTEN BY
C1         P.R.DAVIS, UNIVERSITY OF ARIZONA.
C
      REAL AX(200),AY(200),HR(200),X(3000),Y(3000),SCL(12),
     1H(3000),XS(3000),YS(3000),HS(3000) ,RDP(200,10)
      INTEGER NRG(200),NA(200),NB(200),NC(200),ND(200),JG(4)
      INTEGER NGA(200),LST(1000)
      DIMENSION TITLE(8), EVENT(8), ALPHA(121),BETA(121)
      READ 115, TITLE
      READ 101, YMIN,YMAX,XMIN,XMAX,SCALE,ROT,PRNT
      PRINT 100
      PRINT 115, TITLE
      PRINT 117
      PRINT 114
      PRINT 116, YMIN,YMAX,XMIN,XMAX,SCALE
      PRINT 117
      DELX=SCALE/10.0
      DELY=SCALE/6.0
      DO 66 I=1,1000
      LST(I)=0
 66   CONTINUE
      DO 37 I=1,200
      HR(I)=0.0
      NRG(I)=0
      NGA(I)=0
 37   CONTINUE
      PTX=0.0
      DO 51 I=1,200
      READ 102, NRG(I),AX(I),AY(I),NA(I),NB(I),NC(I),ND(I)
      IF(NRG(I).EQ.0) GO TO 59
      MR=I
      J=NRG(I)
      IF(LST(J).NE.0) GO TO 80
      LST(J)=I
 51   CONTINUE
 59   IF(ROT.EQ.0.0) GO TO 60
      DO 75 I=1,MR
      TEMP=AX(I)
      AX(I)=AY(I)
      AY(I)=-TEMP
```

```
75    CONTINUE
      TEMP=XMIN
      TEMA=XMAX
      XMIN=YMIN
      XMAX=YMAX
      YMIN=-TEMA
      YMAX=-TEMP
60    READ 115, (EVENT(J),J=1,7)
      IF(EOF,1) 73,74
74    READ 101, DELH
      NAV=2999-MR
      DO 34 I=1,200
      LST(I)=IABS(LST(I))
34    CONTINUE
      DO 68 I=1,200
      READ 105,NGA(I),(RDP(I,J),J=1,7)
      IF(NGA(I).EQ.0)GO TO 35
      JR=NGA(I)
      IF(LST(JR).LT.0) GO TO 81
      LST(JR)=-LST(JR)
      MGA=I
68    CONTINUE
35    DO 50 NEV=1,7
      IF (NEV.EQ.4) GO TO 50
      PRINT 100
      PRINT 141,TITLE,EVENT(NEV)
      PRINT 117
      DO 70 I=1,MGA
      NR=NGA(I)
      RF=RDP(I,NEV)
      IF (I.EQ.1) HMX = RF
      IF(RF.GT.HMX) HMX = RF
      IF(LST(NR).EQ.0) PRINT 118,NR
      IF(LST(NR).EQ.0) GO TO 70
      JR=-LST(NR)
      HR(JR)=RF
70    CONTINUE
      PRINT 117
      IF(HMX.EQ.0.0) GO TO 60
      HST = HMX + 100.0*DELH
      ALM=DELH*0.001
      NP=0
      DO 54 I=1,MR
      JB=NRG(I)
      IF(LST(JB).GE.0) PRINT 120, JB
      IF(LST(JB).GE.0) GO TO 54
      JG(1)= NA(I)
      JG(2)= NB(I)
      JG(3)= NC(I)
      JG(4)= ND(I)
      DO 55 J=1,4
      IF (JG(J).EQ.0) GO TO 55
      JM=JG(J)
      IF(LST(JM).GE.0) PRINT 121,JB,JM
      IF(LST(JM).GE.0) GO TO 55
      JA=-LST(JM)
      DIFX=AX(JA)-AX(I)
      DIFH=HR(JA)-HR(I)
      DIFY=AY(JA)-AY(I)
      DABH=ABS(DIFH)
      IF(DABH.LT.ALM) GO TO 55
      IF(HR(I).GT.HR(JA)) GO TO 61
      XCL=HR(I)/DELH-0.2
      XCV=HR(JA)/DELH+0.2
      GO TO 62
 61   XCL=HR(JA)/DELH-0.2
      XCV=HR(I)/DELH+0.2
 62   NCL=XCL+1.0
      NCV=XCV
      IF(NCL.GT.NCV) GO TO 55
      DO 56 K=NCL,NCV
      NP=NP+1
      H(NP)=DELH*FLOAT(K)
      X(NP)=AX(I)+(H(NP)-HR(I))*DIFX/DIFH
      Y(NP)=AY(I)+(H(NP)-HR(I))*DIFY/DIFH
      IF (AX(I).EQ.AX(JA)) GO TO 79
      IF (X(NP).LE.AX(JA).AND.X(NP).GE.AX(I)) GO TO 49
      IF (X(NP).GE.AX(JA).AND.X(NP).LE.AX(I)) GO TO 49
      XID=ABS(X(NP)-AX(I))
      XJD=ABS(X(NP)-AX(JA))
      XDL=2.0*DELX
      XDM=ABS(0.03*DIFX)
      GO TO 67
 79   IF(Y(NP).LE.AY(JA).AND.Y(NP).GE.AY(I)) GO TO 49
      IF(Y(NP).GE.AY(JA).AND.Y(NP).LE.AY(I)) GO TO 49
      XID=ABS(Y(NP)-AY(I))
      XJD=ABS(Y(NP)-AY(JA))
      XDL=2.0*DELY
      XDM=ABS(0.03*DIFY)
 67   IF(XJD.LT.XID)XID=XJD
      IF(XDL.LT.XDM) XDL=XDM
      IF(XID.GT.XDL)NP=NP-1
 49   CONTINUE
      IF(NP.EQ.NAV) GO TO 64
 56   CONTINUE
 55   CONTINUE
 54   CONTINUE
 45   PRINT 100
      PRINT 141,TITLE,EVENT(NEV)
      PRINT 117
      PRINT 128
      PRINT 126
      M=0
      DO 46 I=1,MR
      J=NRG(I)
      IF (LST(J).GE.0) GO TO 46
      NP = NP + 1
      X(NP) = AX(I)
      Y(NP) = AY(I)
      H(NP) = HST
      M=M+1
      TEMP=-AY(I)
      IF (ROT.EQ.0.0) PRINT 110, NRG(I),AX(I),AY(I),HR(I)
      IF (ROT.NE.0.0) PRINT 110, NRG(I), TEMP,AX(I),HR(I)
46    CONTINUE
      NP=NP+1
      X(NP)=XMIN+DELX*5.0
      Y(NP)=YMIN-DELY*5.0
      H(NP)=HST
      PRINT 117
      PRINT 123, DELH
      PRINT 117
      PRINT 135,M
      IF (PRNT.EQ.0) GO TO 33
      PRINT 100
      PRINT 141.TITLE,EVENT(NEV)
      PRINT 117
      PRINT 129
      PRINT 127
33    M=0
      DO 57 J=1,NP
      YS(J)=YMIN-DELY*8.0
      DO 58 I=1,NP
      IF(Y(I).LT.YS(J)) GO TO 58
      YS(J)=Y(I)
      NS=I
58    CONTINUE
      Y(NS)=YMIN-DELY*10.0
      XS(J)=X(NS)
      HS(J)=H(NS)
      IF (HS(J).EQ.HST) GO TO 57
      M=M+1
      IF (PRNT.EQ.0.0) GO TO 57
      TEMP=-YS(J)
      IF (ROT.EQ.0) PRINT 110,M,XS(J),YS(J),HS(J)
      IF (ROT.NE.0) PRINT 110,M,TEMP,XS(J),HS(J)
57    CONTINUE
      PRINT 117
      PRINT 132.M
      DO 31 I=1,121
      BETA(I)=1H-
31    CONTINUE
      DO 32 I=1,121,10
      BETA(I)=1H+
32    CONTINUE
      WEST=XMIN
```

```
28    EAST=WEST+120.0*DELX
      SCL(1)=WEST
      DO 30 I=2,12
      SCL(I)=SCL(I-1)+10.0*DELX
30    CONTINUE
      PRINT 151.SCL
      PRL=YMAX-0.5*DELY
      PNL=YMAX
      IF(ROT.NE.0.0) PNL=-PNL
      PRINT 137, PNL,BETA
      L=0
38    PRL=PRL-DELY
      PNL=PRL+0.5*DELY
      IF (ROT.NE.0.0) PNL=-PNL
      DO 36 I=1,121
      ALPHA(I)=1H
36    CONTINUE
      IF(YMIN.GE.PRL) GO TO 48
42    L=L+1
      IF(YS(L).LT.PRL) GO TO 43
      IF(XS(L).LE.EAST.AND.XS(L).GE.WEST) GO TO 40
      GO TO 42
40    XI=(XS(L)-WEST)/DELX+0.5
      I=XI+1
      IF(ALPHA(I).NE.1H  ) I=I+1
      IF(ALPHA(I).NE.1H  ) I=I-2
      IF(I.LT.1) I=1
      IF(I.GT.121) I=121
      IF (HS(L).EQ. HST) GO TO 63
      XDIF=HS(L)/DELH
      KDIF=XDIF
      RMD=XDIF-KDIF
      IF (RMD.GT.0.5)KDIF=KDIF+1
      IF (KDIF.EQ.0)GO TO 26
      IF(KDIF.LE.26) GO TO 41
      IM=MOD(KDIF,26)
      IF(IM.NE.0) GO TO 29
      GO TO 26
29    NK=KDIF/26
      KDIF=KDIF-NK*26
41    GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
     1,24,25,26),KDIF
63    ALPHA(I)=1H*
      GO TO 42
    1 ALPHA(I)=1HA
      GO TO 42
    2 ALPHA(I)=1HB
      GO TO 42
    3 ALPHA(I)=1HC
      GO TO 42
    4 ALPHA(I)=1HD
      GO TO 42
    5 ALPHA(I)=1HE
      GO TO 42
    6 ALPHA(I)=1HF
      GO TO 42
    7 ALPHA(I)=1HG
      GO TO 42
    8 ALPHA(I)=1HH
      GO TO 42
    9 ALPHA(I)=1HI
      GO TO 42
   10 ALPHA(I)=1HJ
      GO TO 42
   11 ALPHA(I)=1HK
      GO TO 42
   12 ALPHA(I)=1HL
      GO TO 42
   13 ALPHA(I)=1HM
      GO TO 42
   14 ALPHA(I)=1HN
      GO TO 42
   15 ALPHA(I)=1HO
      GO TO 42
   16 ALPHA(I)=1HP
      GO TO 42
   17 ALPHA(I)=1HQ
      GO TO 42
   18 ALPHA(I)=1HR
      GO TO 42
   19 ALPHA(I)=1HS
      GO TO 42
   20 ALPHA(I)=1HT
      GO TO 42
   21 ALPHA(I)=1HU
      GO TO 42
   22 ALPHA(I)=1HV
      GO TO 42
   23 ALPHA(I)=1HW
      GO TO 42
   24 ALPHA(I)=1HX
      GO TO 42
   25 ALPHA(I)=1HY
      GO TO 42
   26 ALPHA(I)=1HZ
      GO TO 42
43    PRINT 145,PNL,ALPHA
      L=L-1
      GO TO 38
48    PRINT 137, PNL, BETA
      PRINT 113, SCL
      IF (ROT.EQ.0.0) PRINT 133
      IF (ROT.NE.0.0) PRINT 134
      PRINT 141, TITLE,EVENT(NEV)
      IF (PTX.GT.0.0) PRINT 125
      PRINT 117
      PRINT 122, SCALE,DELH
      PRINT 117
      ASTR=1H*
      PRINT 130,ASTR
      PRINT 131
      IF(EAST.GE.XMAX) GO TO 50
      WEST=EAST
      GO TO 28
50    CONTINUE
      GO TO 60
73    PRINT 142
      GO TO 27
64    PRINT 125
      PTX=1.0
      GO TO 45
80    PRINT 124,J
      GO TO 82
81    PRINT 119, NR
82    PRINT 140
27    STOP
100   FORMAT(*1*)
101   FORMAT(8F10.0)
102   FORMAT(I10,2F10.0,4I5)
105   FORMAT(I10,7F10.0)
110   FORMAT(I12,3F15.4)
113   FORMAT(/,7X,12F10.3,)
114   FORMAT(7X,4HYMIN,8X,4HYMAX,8X,4HXMIN,8X,4HXMAX,7X,5HSCALE)
115   FORMAT(8A10)
116   FORMAT(6F12.4)
117   FORMAT(//)
118   FORMAT (5X,21HRAINFALL FOR GAGE NO.,I6,
     1 41H  NOT USED, COORDINATES OF GAGE NOT GIVEN)
119   FORMAT(5X,50HMORE THAN ONE RAINFALL VALUE IS GIVEN FOR GAGE NO.,
     1I5)
120   FORMAT(5X,35HNO RAINFALL DATA GIVEN FOR GAGE NO.,I5)
121   FORMAT(5X,27HINTERPOLATION FROM GAGE NO.,I5,13H  TO GAGE NO.,I5,
     1 23H  CANNOT BE CARRIED OUT)
122   FORMAT(5X,14HSCALE OF MAP  ,F10.4,16H  MILES = 1 INCH,30X,
     1 27HINTERVAL BETWEEN ISOHYETS =,F9.3,6H  INCH)
123   FORMAT(5X,27HINTERVAL BETWEEN ISOHYETS =,F9.3,6H  INCH)
124   FORMAT(5X,23HCOORDINATES OF GAGE NO,I5,
     1 26H  ARE GIVEN MORE THAN ONCE)
125   FORMAT(10X,46HNUMBER OF INTERPOLATED POINTS EXCEEDS CAPACITY)
126   FORMAT(10X,2HRG,12X,1HX,14X,1HY,10X,4HRAIN/)
127   FORMAT(10X,2HPT,12X,1HX,14X,1HY,10X,4HRAIN/)
128   FORMAT(10X,36HORIGINAL DATA USED FOR INTERPOLATION//)
129   FORMAT(10X,12HINTERPOLATED DATA//)
130   FORMAT(5X,32HRAIN GAGE LOCATION DENOTED BY   ,1A1 )
131   FORMAT(5X,36HISOHYETAL POINTS DENOTED BY LETTERS )
132   FORMAT(5X,38HTHE NUMBER OF INTERPOLATED POINTS IS  ,I6)
```

```
133  FORMAT (/90X,13HX AXIS  MILES/)
134  FORMAT (/90X,13HY AXIS  MILES/)
135  FORMAT(5X,44HTHE NUMBER OF RAIN GAGING STATIONS USED IS  ,I5)
137  FORMAT(1X,F8.3,3X,1HI,121A1,1HI)
140  FORMAT(5X,32H DUPLICATE DATA, PROGRAM STOPPED)
141  FORMAT(5X,8A10,/,5X,1A10)
142  FORMAT(10X,11HEND OF DATA)
145  FORMAT(1X,F8.3,3X,1HI,121A1,1HI)
151  FORMAT(1H1,7X,12F10.3,/)
     END
```